PREDICTIVE LATERAL LOGIC FOR NUMERICAL ENTRY GUIDANCE ALGORITHMS

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NUMERICAL ENTRY GUIDANCE

- Defined as entry guidance algorithms which eschew analytical approximations in favor of direct numerical integration of the equations of motion to evaluate candidate control profiles.

- Recent Examples: Fully Numerical Predictive Entry Guidance (Lu), PredGuid (Draper Labs), et cetera.

LATERAL LOGIC

- For guided entry vehicles that control range flown primarily via bank angle commanding (Gemini, Apollo, Shuttle, Mars Science Laboratory, Orion, etc.), the downrange problem is typically treated largely independently of the crossrange problem.

- Typically, the longitudinal channel (downrange) is de-coupled form the lateral channel (crossrange).

- For all the vehicles listed above, the lateral logic mechanism has always relied on the concept of violating angular error deadbands (lateral angle error or azimuth error) relative to the target.

- When these deadbands are violated, a bank reversal is commanded.

COMMON LATERAL LOGIC SCHEME

- Deadbands are almost always a function of speed or speed squared.
- $Lat_{DB} = c_0 + c_1 V^2$
  - c_0 and c_1 are coefficients, typically determined by empirical tuning.
- If the deadbands are too tight, then many bank reversals will occur (expending propellant) and the downrange guidance performance will suffer.
- If the deadbands are too loose, then the vehicle runs the risk of not being able to recover and make it back to the target.

FAMILIES OF LATERAL LOGIC ALGORITHMS

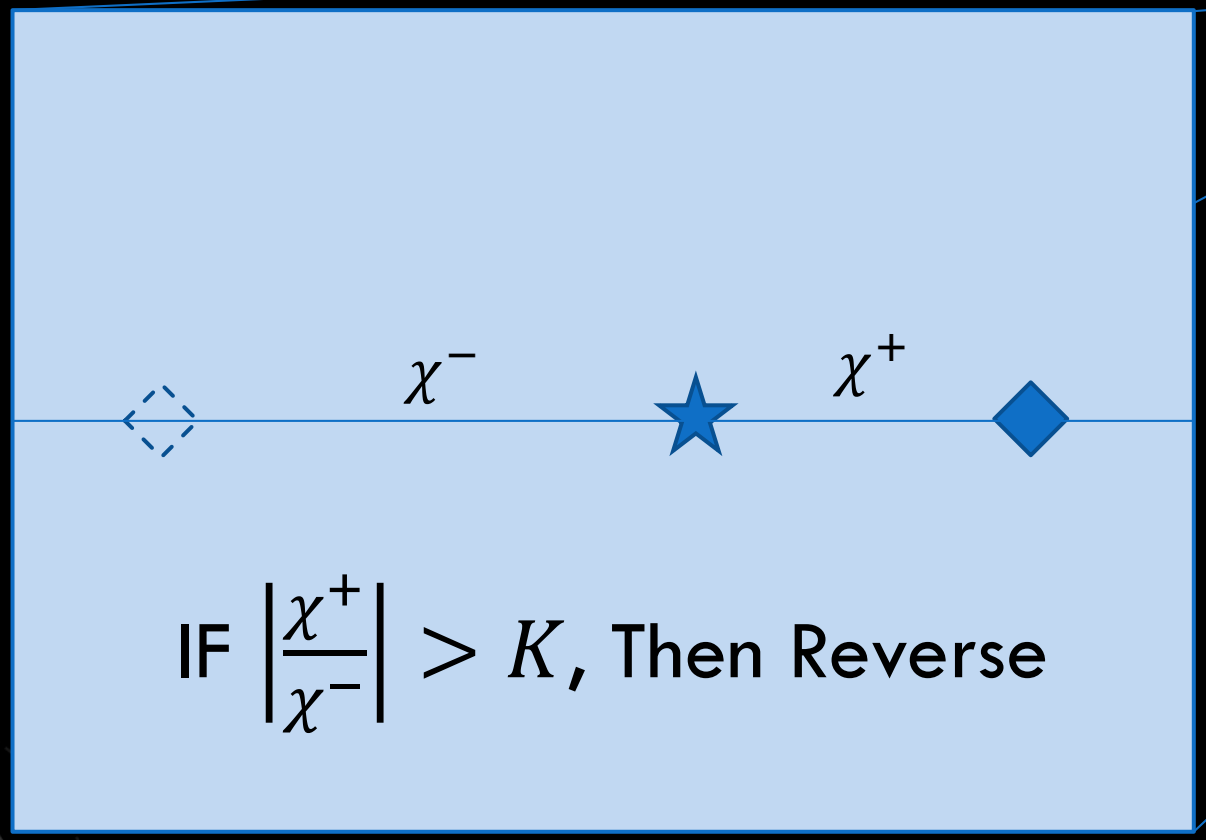
- Deadbands (random number of bank reversals)
- 1-Bank Reversal Schemes
- 2-Bank Reversal Schemes

MANUAL PILOTING INSPIRATION

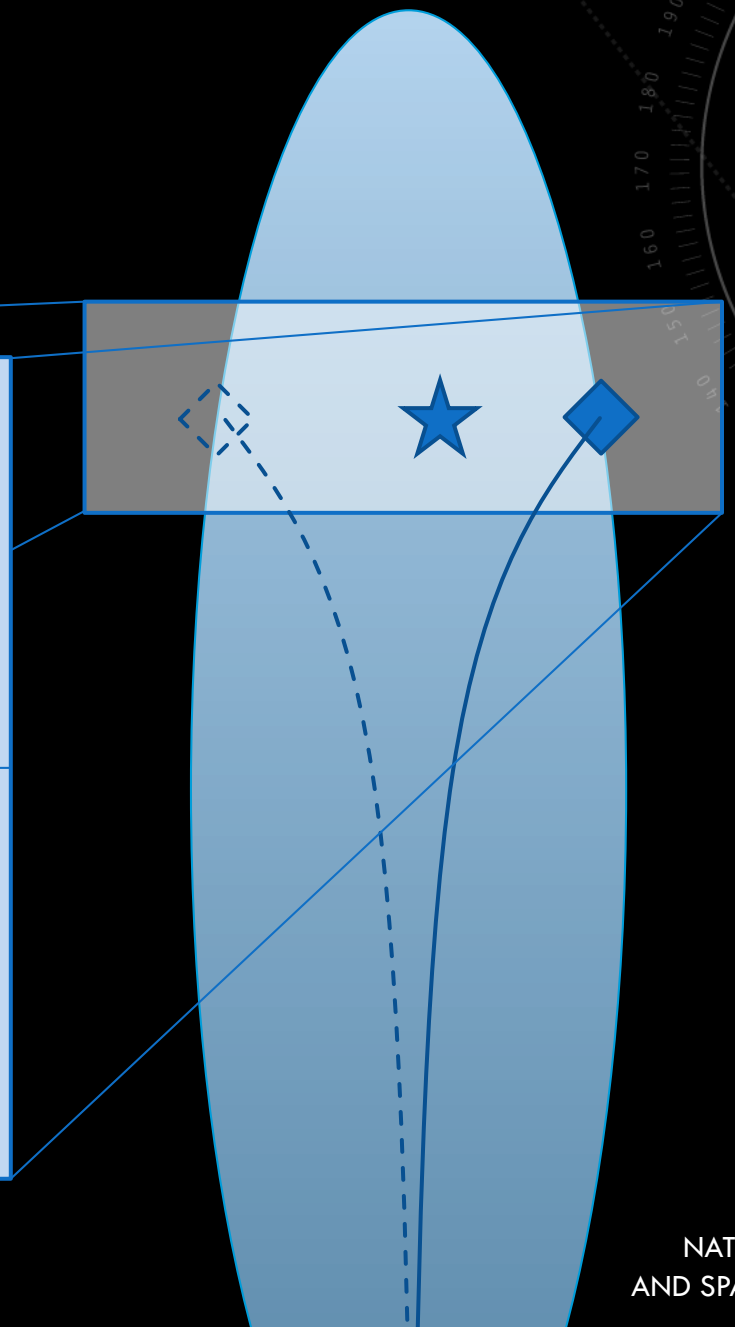
- How would I fly a capsule to manage crossrange?

- Note that the footprint is constantly contracting toward the current aimpoint.
  - If no reversals are performed, then the target will “fall” outside the footprint.

BANK REVERSAL INTUITION



IF $\left|\frac{\chi^+}{\chi^-}\right| > K$, Then Reverse



CROSSRANGE ERROR AFTER N REVERSALS

$$\chi_f = \frac{\chi_0}{K^n}$$

FIXED NUMBER OF REVERSALS

- Re-arranging, we can solve for what K should be to achieve some crossrange error tolerance at time $t = t_f$, some terminal crossrange error at $t = 0$, and the number of bank reversals n.

$$K = \frac{1}{\sqrt[n]{\frac{\chi_f}{\chi_0}}}$$

- The expression can easily be adapted for a closed-loop form.

- **This implementation allows for a guaranteed, fixed number of reversals to be performed.**

$$\boxed{K(t) = \frac{1}{\sqrt[n]{\frac{\chi_f}{\chi(t)}}}}$$

Closed-loop

BENEFITS

- With a fixed number of reversals, the propellant consumption can be better estimated during entry, allowing propellant tanks to be sized smaller. Smaller tanks translate into dry mass savings.
- This approach allows the user to “dial-in” the number of reversals. The crew/ground could even change the number of reversals “on-the-fly” to respond to fuel leaks, etc.
- Directly trade propellant usage for landing accuracy robustness.

Predictive Lateral Logic Visualized in Google Earth

Scenario: Targeting (fictitious) landing site in Lake Superior.

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SUMMARY

- Predictive Lateral Logic has been developed which permits a fixed number of bank reversals.
- Constraining this number contracts propellant use variability, potentially reducing tank sizing (dry mass reduction).
- Intended to be used as a “plug-n-play” simple algorithm for numerical entry guidance algorithms.